Three-dimensional Analysis of the Root Canal Preparation with Reciproc Blue, WaveOne Gold and XP EndoShaper. A New Method in vivo

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Abstract

Background: Evaluation of changes in volume after root canal preparation. with single file rotary systems such as Reciproc-Blue, WaveOne-Gold and XP-EndoShaper, with a new in vivo study model using CBCT and 3D reconstructions on patients

Methods: Thirty human lower premolars were randomly divided into three groups, in which the root canals were prepared using one of these single-file systems: Reciproc-Blue, WaveOne-Gold and XP-EndoShaper. Root canals were scanned before and after root canal preparation using CBCT, and a 3D reconstruction was performed with RHINOCEROS 5.0 software to assess the increase in canal volume for each group after instrumentation. The Anova test was used to determine statistically significant differences between the groups and Post-hoc Tukey's-test to compare the groups with each other.

Results: The proposed 3D-reconstruction model allows to measure the variation of the volume within the root canal of the premolars studied. With this model, Reciproc-Blue showed higher increase in canal volume, followed by WaveOne-Gold and XP-EndoShaper (Anova $p = 0.003$). XP-EndoShaper did not show a statistically significant increase in canal volume after root canal preparation (Tukey's test for paired data $p = 0.06$ confirmed the results with each other).

Conclusion: it is possible to use CBCT and 3D reconstruction as a model to study the preparation quality of the root canal in vivo. With this model, Reciproc-Blue showed higher increase in root canal volume, followed by WaveOne-Gold, while XP-EndoShaper did not significantly increase root canal volume during preparation.

Background

Optimal endodontic preparation aims to preserve the original morphology of root canals, respecting the size and spatial position of the apical foramen [1]. Operative Procedural Errors, such as over instrumentation and poor instrumentation could lead to alterations in the canal volume [2–4].

The internal cross-section anatomy of root canals has different shapes and sizes, being oval shapes the most common at the cervical and middle thirds, while rounded shapes are more common at the apical third. These variations in the internal anatomy of the canal makes cleaning and disinfecting difficult [5, 6]. Usually, rotary systems tend to generate a round preparation in oval canals, leaving 5–80% of the walls unprepared, compromising the quality of the preparation which is based on maintaining the original shape of the canal [7].

On the other hand, in order to minimize procedure errors during root canal treatments, new rotary instruments have been designed claiming to adapt better to the root anatomy. Therefore, it is essential to study how is their performance inside the canal, such as The Reciproc Blue single-file system (VDW, Munich, Germany), WaveOne Gold (Dentsply/Maillefer, Ballaigues, Switzerland) and XP Endo-Shaper (FKG/Dentaire, La-Chaux-de-Fonds, Switzerland) these files have been designed with different variations

of the Ni-Ti alloys to improve their characteristics, providing greater strength and elasticity to the instruments and therefore reducing complications and procedural errors, seeking to maintain the original shape of the canal [8, 9].

Many studies have been conducted to evaluate root canal preparation [1, 3–5]. All of these have tested different files systems.[1,3–5] And always used ex vivo models, such as simulated canals [1, 4] and extracted teeth [3, 5] to observe the variation created within the root canal. The methods used in these studies was the Micro CT which has been considered the gold standard in 3D reconstruction method to evaluate prepared root canals [3, 5], although this technology is inapplicable in patients, the results have been taken and considered certain and applied to the clinical practice.

This study pretends to validate an in vivo model with a precise methodology, based on the use of cone-beam computed tomography (CBCT), which provides three-dimensional digital images with a reproducible and non-invasive method, achieving great precision, high resolution, significant reduction of exposure time and low radiation dose. It allows to evaluate different anatomical aspects in relation to root canal preparation, eliminating the superposition of images. Recent in vivo studies have reported greater sensitivity and specificity to obtain images for diagnosis purposes and the analysis of the radicular anatomy, as they have greater resemblance and application to clinical practice [10, 11]. These images can be used to generate 3D reconstruction images with different design programs.

The model proposed also used the Rhinoceros 5.0 3D program (Robert McNeel & Associates, Washington, USA), which is a software tool for drawing and modelling in 3D used in naval engineering that allows to reconstruct curves and surfaces, creating polygonal meshes of real objects, and therefore is possible to reconstruct precise pre-instrumentation and post-instrumentation anatomies of the root canal [12, 13]. Thus, Rhino allow produce mathematical precise representation of freeform surfaces and curves in computer graphics which could be very useful for 3D reconstruction of teeth and root canals. This software has been successfully tested in medical [14, 15] and dental applications [16–18].

Therefore, the purpose of this research is to present a novel method to evaluate the quality of root canal preparations using 3D reconstruction of CBCTs in patients. To achieve this objective, we selected 3 different single-file systems: Reciproc Blue, WaveOne Gold and XP Endo-Shaper to measure canal volume increase after root canal preparation in human premolars.

Methods

An in vivo experimental study was performed according to the resolution 8430 from the Colombian Ministry of Health regarding ethical issues in research involving human tissues, and was approved by the bioethics committee of the University Colegios de Colombia (RN27/02/22/2017). Written informed consent was obtained from each patient participating in the study (18-30 years old, healthy, not medicated, and non-smoking human donors). This study was made following the guidelines of use of CBCT in research on human beings based on the evidence on when to use it in Endodontics [19]. in

patients who need double CBCT. one for diagnosis and the other for the control of orthodontic treatment of dento-maxillofacial anomalies such as maxillary and mandibular asymmetries [20].

Thirty lower premolars from healthy humans were used, in which extraction was indicated for orthodontic reasons. All the teeth used were caries- and restoration-free with complete root development determined both visually and radiographically, without signs of periodontal disease or traumatic occlusion and without orthodontic forces. Teeth had only one straight canal (canal curvatures over 25º were not included). Each premolar was assigned randomly for one of the experimental groups, consisting of 10 premolars each: a) Reciproc Blue (VDW, Munich, Germany); b) WaveOne Gold (Dentsply/Maillefer, Ballaigues, Switzerland); and c) XP EndoShaper (FKG/Dentaire, La-Chaux-de-Fonds, Switzerland). The sample size was estimated based on the behaviour of variables and confirmed with the TAMAMU 1.1® program (Tokyo, Japan)

An initial CBCT was taken for each premolar with the Carestream Dental CS 8100 3D (CARECAPITAL ADVISORS LIMITED / Rochester, New York, United States), with a 100 kVp voltage and 3-8 mGy / cm2 current. The scan time was approximately 10 seconds for each premolar. Images were analyzed with the Nobel-clinician software (Nobel Biocare Inc, USA). At the axial plane, slices were made at 0.5mm, 1mm, 2mm, 3mm, 4mm, 5mm, 6mm and 7mm, and measures of the root canal and the root were taken from vestibular to palatal and from mesial to distal for three-dimensional reconstruction. Snapshot images of the different sections were imported with the Rhinoceros 3D 5.0 software (Robert McNeel & Associates, Washington, USA) to draw the canal and the root using the poly-line command (Fig. 1 and 2). A digital file in 3dm format was obtained with the reconstruction of the sample previous to root canal preparation [10, 12] (Fig. 3).

Preparation of experimental samples:

All patients underwent prophylaxis with hydrogen peroxide and prophylactic brush, then they were anaesthetized with an inferior alveolar nerve block technique using 1.8 mL of 4% prilocaine without vasoconstrictor. Rubber dam isolation was placed and the cavity access was performed with a Zekrya bur. Canal patency was confirmed with a #10 K file (Dentsply/Maillefer, Ballaigues, Switzerland), working length was established (at -0.5 mm from apical foramen) with the Root ZX apex locator (J Morita, Japan) and verified with a periapical radiography. The root canal samples were prepared with the correspondent technique for each group following the manufacturer's instructions, using a VDW Silver Reciproc endodontic motor (VDW, Munich, Germany) as follows:

Reciproc Blue group:

The root canal was prepared using one new Reciproc Blue file (VDW, Munich, Germany) (size 25, 0.08 taper) activated in a VDW Silver Reciproc motor (VDW, Munich, Germany), set at the RECIPROC ALL program, following the manufacturer's recommendations. The file was used with short up and down

motion with slight apical pressure in three cycles, one to prepare each third of the canal (cervical, middle and apical). After each cycle, the file was cleaned with wet gauze to remove dentine debris, and the canal was irrigated with 3 mL of 5.25% sodium hypochlorite (NaOCl) using a Monoject syringe with a 30-gauge needle placed 2 mm short of working length to complete a total of 9 mL of NaOCl for each canal. Effective working time of the file inside the canal did not exceed 1 min.

WaveOne Gold group:

The root canal was prepared using one new WaveOne Gold primary file (Dentsply/Maillefer, Ballaigues, Switzerland) (size 25, 0.07 taper) activated in a VDW Silver Reciproc motor (VDW, Munich, Germany), set at the WAVEONE ALL program, following the manufacturer's recommendations. Irrigation volume and effective working time of the file inside the canal were the same as described for the Reciproc Blue group.

XP EndoShaper group:

The root canal was prepared using one new XP EndoShaper (FKG/Dentaire, La-Chaux-de-Fonds, Switzerland). (size 30, 0.01 taper) activated in a VDW silver motor (VDW, Munich, Germany) strictly following the manufacturer's recommendations. Irrigation volume and effective working time of the file inside the canal were the same as described for the Reciproc Blue and WaveOne Gold groups.

Post-preparation tomographic analysis:

A second tomographic analysis was performed with CBCT. Taking advantage of orthodontic control for dento-maxillofacial anomalies presented in the selected patients that needs to be followed up. Following the same steps as the initial CBCT, a digital file in 3dm format was obtained with the reconstruction of the sample after root canal preparation to carry out the superposition of preparation images before and after in order to evaluate the variables proposed in the study.

Pre- and post-operative dental reconstruction process:

Sixty CBCT scans of the teeth were obtained from before and after root canal preparations with slices at 0.5, 1, 2, 3, 4, 5, 6 and 7 mm with Rhinoceros 3D. The tomography was framed with the poly-line command, to be used later as a reference point. These slices with the frame were exported to the Rhinoceros software (Robert McNeel & Associates, Washington, USA) one by one, both of the root and the canal. Also, a reference line was drawn connecting the point of intersection of the aforementioned lines in the root and the canal, to make sure that the position of the canal inside the root was not altered in the previous steps (Fig. 4).

Superimposition of pre- and post-preparation reconstruction:

With the guide lines and the table of measurements, each root and canal was given its corresponding measure in μm with the scale 1D command, enlarging or reducing the drawing according to the table of measurements. All the reference lines used were removed to clean the drawing and when all the slices were scaled, it was proceeded to join each pre-operative slice to its corresponding original millimeter, this was done with the move command using as reference points, both the frame of the tomography that was preserved at the beginning and the root itself (Fig. 5).

The above procedure reduces the number of slices to 6 and in each root the canal was located both before and after the endodontic preparation. The next step was to place the three dimensionally slices on top of each other at the corresponding heights with the move command, giving a diagram of millimeter by millimeter heights of the root and the canal. When having the slices in this position, a complex surface was created between all slices for each element with the loft command and the result was a surface for the root, one for the original canal and one for the prepared canal (Fig 6).

Three surfaces remain that are then covered with the plane and split commands to generate a solid form, finally the edge of the canals is created following an hourglass shape with the loft command, this was covered with the commands mentioned above and finally, details such as the colors and the transparency of the root were added with the material editor command (Fig. 7 and 8).

Measurement of canal volume:

The total volume of the root canal was measured before and after root canal preparation by using the volume command in the Rhinoceros 5.0 software. This function gives the volume result of a solid in mm^3. Student t test analysis for paired data were used to determine statistically significant differences between the before and after canal volumes. Percentage of volume increase was also calculated to compare the volume increase for each group. Anova test was used to determine statistically significant differences in the percentage of canal volume increase between the experimental groups.

Results

All experimental teeth could be successfully 3D digitalized through Rhino software (Robert McNeel & Associates, Washington, USA). These images showed clearly the cutting ability of the three types of files systems tested, by the superimposition of the canal reconstruction before and after the canal preparation.

Table 1 shows the comparison between the initial volume of the canal prior to the instrumentation procedure and the final volume after preparation. There was no statistically significant difference between the volume of the pre-instrumented canals that were assigned to each group ($p = 0.87$) so that the 3 instruments worked in similar canals. Student t test analysis for paired data revealed that

statistically significant differences were found in the Reciproc Blue and WaveOne Gold groups ($p < 0.001$). The XP EndoShaper group did not show significant differences between the canal volume before and after the instrumentation ($p = 0.06$).

Table 1

Canal Volume in mm^3 before and after preparation with three different systems.

	N	Canal volume before preparation*	Canal volume after preparation**	Paired T-student
Reciproc Blue***	10	8.158 ± 5.16	14.692 ± 6.37	$p < 0.001$
WaveOne Gold****	10	7.527 ± 3.47	10.933 ± 2.65	$p < 0.001$
XP EndoShaper****	10	8.638 ± 4.53	9.873 ± 4.74	$p = 0.06$
* Anova $p = 0.87$				
**Anova $p = 0.03$				
***Tukey post-hoc test showed significant difference between Reciproc Blue and the other two systems ($p > 0.05$).				
****No significant differences were observed between WaveOne Gold and XP EndoShaper ($p > 0.05$).				

Additionally, the percentage of canal volume increase was calculated after preparation with each system. Table 2 shows that Reciproc Blue produces the largest increase in canal volume with an average increase of 110.34% ± 72.4%, followed by WaveOne Gold with an average increase of 81.60% ± 63.6%. XP EndoShaper produced the least volume increase with an average of 17.55% ± 9.6%. ANOVA test showed statistically significant differences between groups ($p = 0.003$). Tukey's test post-hoc comparisons revealed statistically significant differences between XP EndoShaper and the two other groups ($p < 0.05$). No significant differences were observed between Reciproc Blue and WaveOne Gold groups ($p = 0.508$).

Table 2
Percentage of canal volume increase after preparation with three different systems.

	N	Mean*	Standard Deviation	Minimum	Maximum
Reciproc Blue**	10	110.34	72.47	51.12	238.20
WaveOne Gold**	10	81.61	63.62	22.22	169.39
XP EndoShaper***	10	1756	9.69	3.46	29.99
* Anova p = 0.003					
** Tukey's post-hoc test didn't show significant differences between Reciproc Blue and WaveOne Gold (p = 0.508).					
***Tukey's post-hoc test showed significant difference between XP EndoShaper and the other two systems (p < 0.05).					

Discussion

The present controlled randomized study describes and uses a new in vivo method that allows obtaining anatomical measurements before and after canal preparation to measure the canal volume increase with 3 different preparation systems: Reciproc Blue (VDW, Munich, Germany), WaveOne Gold (Dentsply/Maillefer, Ballaigues, Switzerland) and XP EndoShaper (FKG/Dentaire, La-Chaux-de-Fonds, Switzerland).

Currently, there are evaluation methods capable of reconstructing the anatomy of the original and prepared root canal, in order to evaluate root canal preparation. However, these are in-vitro and ex-vivo methods such as the Micro-Computed Tomography (micro-CT), which provided significant advances in the three-dimensional reconstruction, with optimal details before, during and after a procedure. Due to its high resolution, it allows to analyze the interior of the evaluated object without damaging it. Unfortunately, it is applicable only to small samples and it cannot be used for in vivo studies in humans [21–23].

In-vitro studies validate techniques and the clinical use of instruments, when they are done under the rigor of the scientific method. These studies help to support clinical models, although their results provide analogies to real situations, they give an idea of what can be expected with the clinical use of the instruments [24]. In contrast, this study was aimed to validate in-vivo results since it presents information in real time with a reliable and trustable method under clinical conditions.

The present study used CBCT as a non-invasive tool that provides high resolution and accurate repeatable three-dimensional images allowing to compare the initial root canal morphology with the canal anatomy after preparation [19, 25]. The images obtained were digitized with the Rhinoceros software (Robert McNeel & Associates, Washington, USA), for the re-construction of the root canal through measurements obtained from the tomographic slices [26]. This software provides a practical

method to record 3D measurements of study models, its accuracy and reliability allow a realistic and effective measurement, with a margin error of less than 1% [12], constituting it as a reliable and accurate tool for this type of studies.

Currently most of the rotating systems are designed aiming to provide a conical preparation of the canal. However, root canal anatomy goes beyond this, since it has been reported that root canals have multiple constrictions, pronounced curvatures and apical foraminas with a diameter that oscillates between 0.30 to 0.47 millimeters [6]. The instruments used for the present investigation present a tip with a diameter of 0.25 for Reciproc Blue (VDW, Munich, Germany), and WaveOne Gold (Dentsply/Maillefer, Ballaigues, Switzerland) and 0.30 for XP EndoShaper (FKG/Dentaire, La-Chaux-de-Fonds, Switzerland).

These file tip diameters are smaller than those of the original anatomy of the canal, generating deficiencies in the debridement of the apical third, which could lead to reduce endodontic therapy success [3]. However, this disadvantage can be compensated due to the reciprocating movement of Reciproc Blue (VDW, Munich, Germany), and WaveOne Gold files (Dentsply/Maillefer, Ballaigues, Switzerland), which due to the greater contact area between the instrument and the canal walls, cut large amounts of dentin [7, 27]. On the other hand, the XP EndoShaper system (FKG/Dentaire, La-Chaux-de-Fonds, Switzerland), because of the novel-ty of its continuous meandering movement together with its booster tip, could generate adequate preparations in accordance with the real diameter of the apical foramen and the root canal [28].

Measurements were made at different root canal levels, from 0.5, 1, 2, 3, 5 and 7 mm from the root apex, considering that, from 0.5 mm to 3 mm, the anatomical shape of the canal lumen is less oval than the rest, which is an important parameter to consider when performing the analysis of the preparation carried out by the different systems. From 5 mm to 7 mm, the anatomical shape of the canal is more oval [6], representing a challenge to the rotary systems to perform an adequate preparation, due to their tendency to make rounded preparations on the root canal walls [3]. This is an important issue to consider, since this study is in vivo, and therefore subject to anatomical variability.

The initial volume of the pre-instrumented canals was similar for the 3 preparation systems (8.158 mm3 for Reciproc Blue (VDW, Munich, Germany), 7.527 mm3 for WaveOne Gold (Dentsply/Maillefer, Ballaigues, Switzerland), and 8.638 mm3 for XP EndoShaper (FKG/Dentaire, La-Chaux-de-Fonds, Switzerland), without showing significant differences between the groups. This analysis is important to verify that the 3 systems worked under similar conditions, in order to guarantee the validity of the results and reducing the bias level [27, 29].

Reciproc Blue (VDW, Munich, Germany), presented an average canal volume increase of 110.34%. This could be explained due to its “S” cross-section that has a good cutting capacity, its 8% taper at its apical third, and to the reciprocating movement that generates an efficient dentine cutting [30]. WaveOne Gold (Dentsply/Maillefer, Ballaigues, Switzerland) also presented good cutting capacity, although lower than Reciproc Blue (VDW, Munich, Germany) but without showing statistically significant differences, probably due to its 7% taper at its apical third, and its parallelogram cross-section [31]. The XP EndoShaper

(FKG/Dentaire, La-Chaux-de-Fonds, Switzerland) presented the smallest change in the volume increase (17.55%) of the three preparation systems showing statistically significant differences with respect to the other two instruments. This may be due to the constant 1% taper of the file, together with its high elasticity MaxWire alloy which provokes the file to lengthen and therefore generating less contact on the canal walls [22], making its behavior unpredictable.

Up to date, this is the first randomized controlled in vivo clinical study that was aimed to compare the single-file rotary instrumentation systems under the proposed study model, where their shaping ability was evaluated by measuring canal volume increase, by taking measurements before and after the in-vivo preparation.

Conclusion

Within the limitations of this study, it can be concluded that the combined use of CBCT and 3D reconstruction with Rhinoceros software, provided an adequate method for the in vivo evaluation of root canal preparation techniques. Of the evaluated systems, Reciproc Blue provides the greatest canal volume increase, followed by WaveOne Gold, while XP EndoShaper does not significant increase canal volume during preparation.

Declarations

- ### Ethics approval and consent to participate:

This study was approved by the ethics committee of the Faculty of Dentistry of the University Colegios de Colombia (RN27/02/22/2017).

- ### Consent for publication:

Not applicable

- ### Availability of data and materials:

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

- ### Competing interests:

The authors declare that they have no competing interests

- ### Funding:

The authors received no specific funding for this work.

Authors' contributions:

JCB Conceptualization, Methodology, Supervision, Project Administration, Writing Original Draft.

NRO Validation, Investigation, Resources.

DU Validation, Investigation, Resources.

CJ Validation, Investigation, Resources.

AP Validation, Investigation, Resources.

JR Validation, Investigation, Resources.

MMAH Validation, Investigation, Resources.

AZM Methodology, Validation.

JFGS Conceptualization, Data Curation, Visualization.

HRM Formal Analysis, Writing Review & Editing.

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Figures

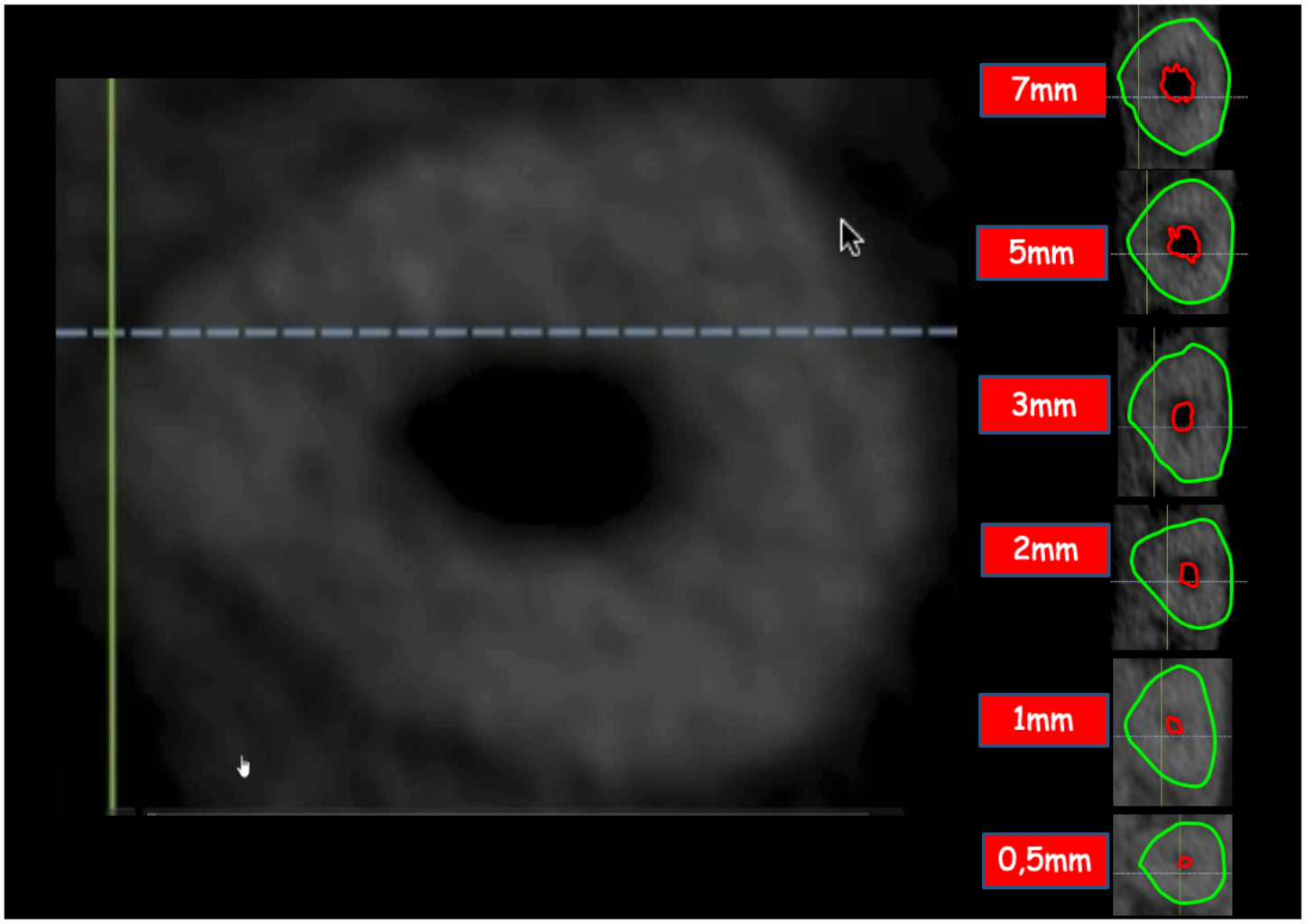

Figure 1

CBCT axial plane slices made at 0.5mm, 1mm, 2mm, 3mm, 4mm, 5mm, 6mm and 7mm, where measures of the root canal and the root were taken for three-dimensional reconstruction. Snapshot images of the different sections were imported with the RHINOCEROS 5.0 3D software to draw the canal and the root.

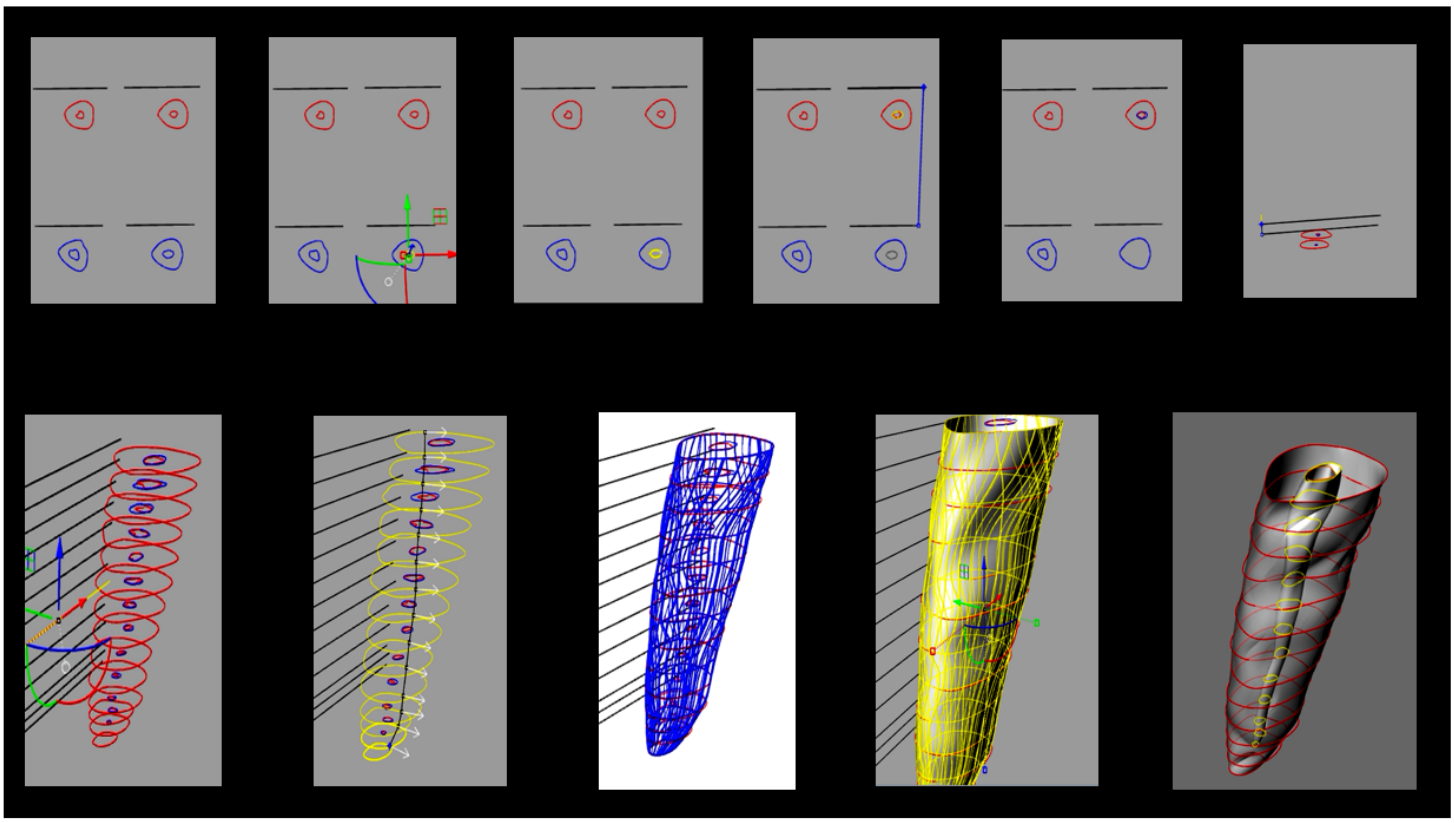

Figure 2

3D-reconstruction procedure step by step.

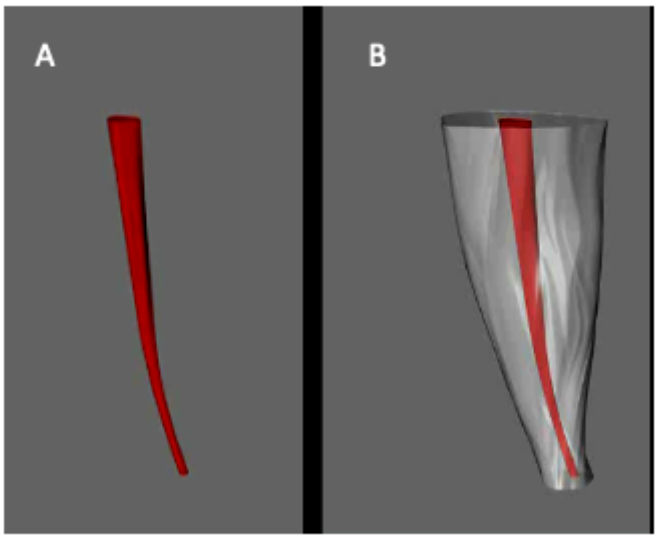

Figure 3

Reconstruction of the sample previous to root canal preparation. A) 3D root canal reconstruction; B) 3D root reconstruction with unprepared canal.

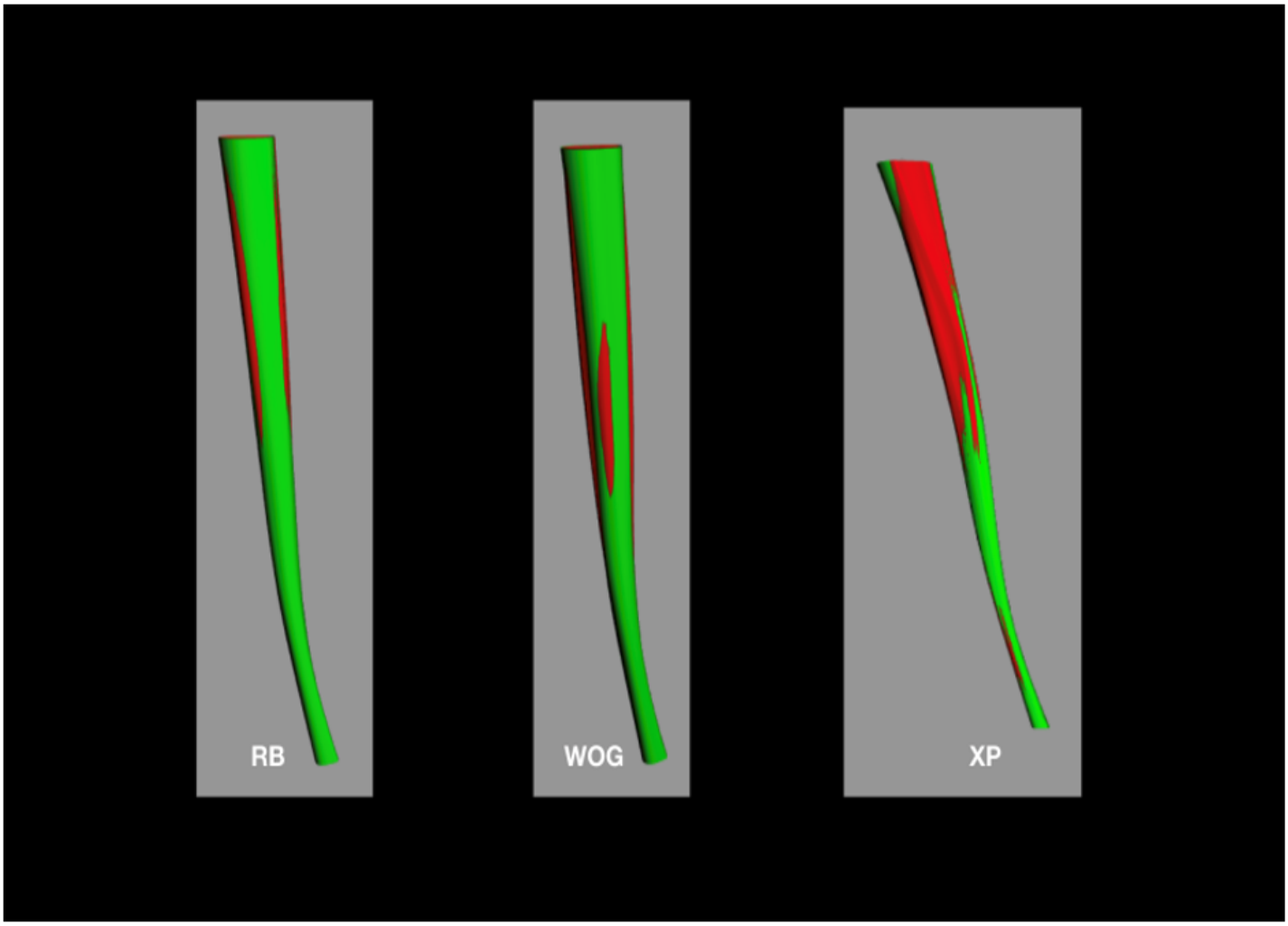

Figure 4

Superimposition of before and after preparation images with different systems. RB= Reciproc Blue; WOG= WaveOne Gold; XP= XP EndoShaper.

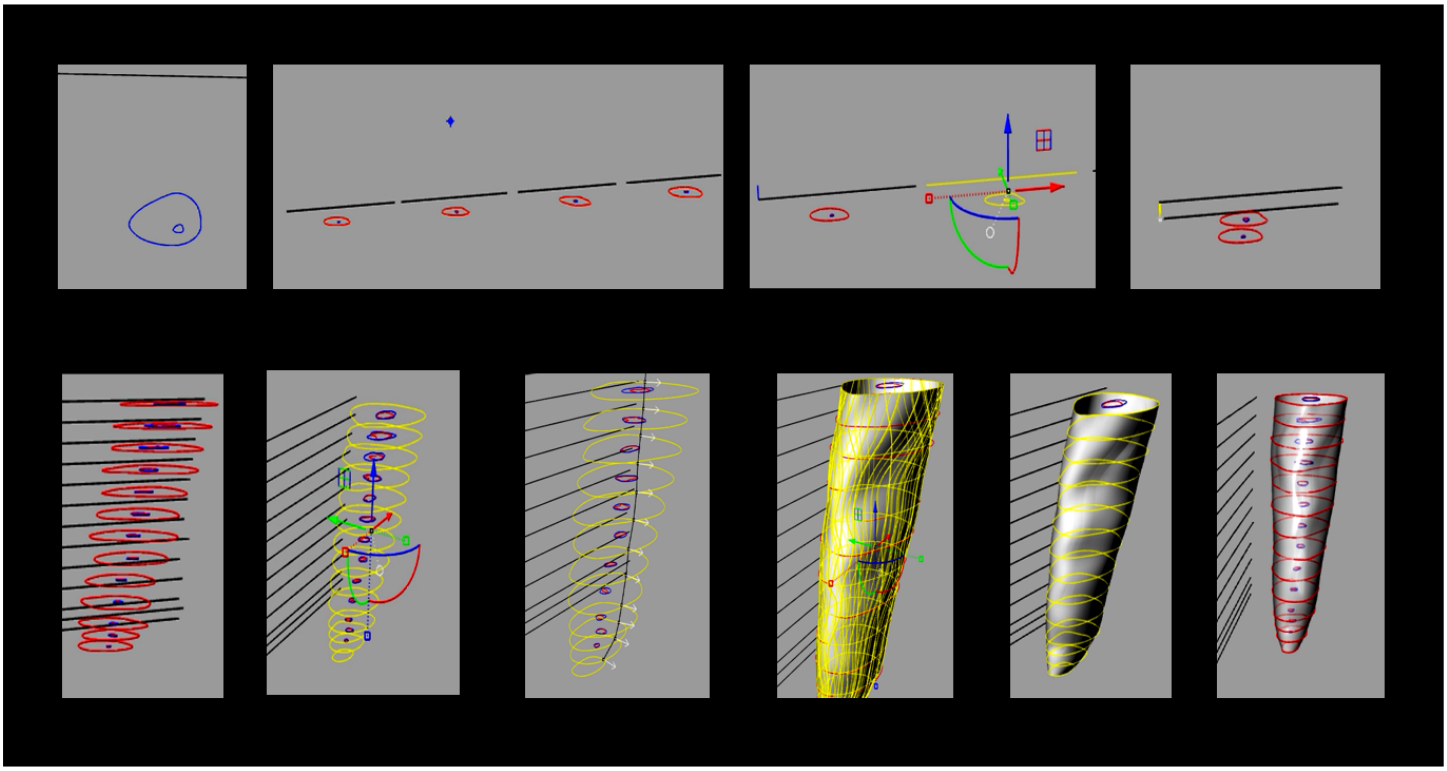

Figure 5

Procedure of superimposition step by step.

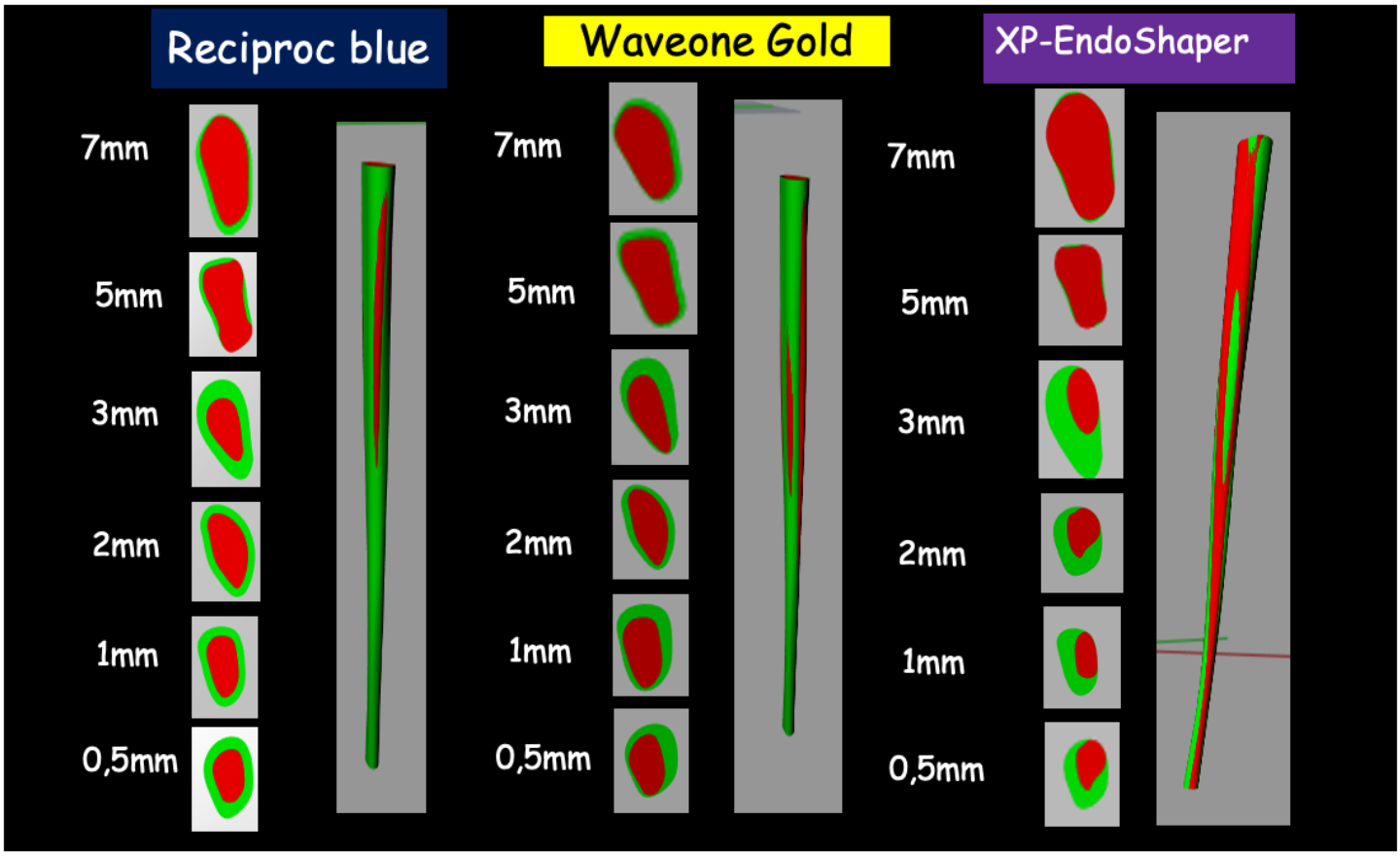

Figure 6

Examples of final 3D reconstructions with details such as the canal colors of teeth prepared with different systems. RB= Reciproc Blue; WOG= WaveOne Gold; XP= XP EndoShaper.

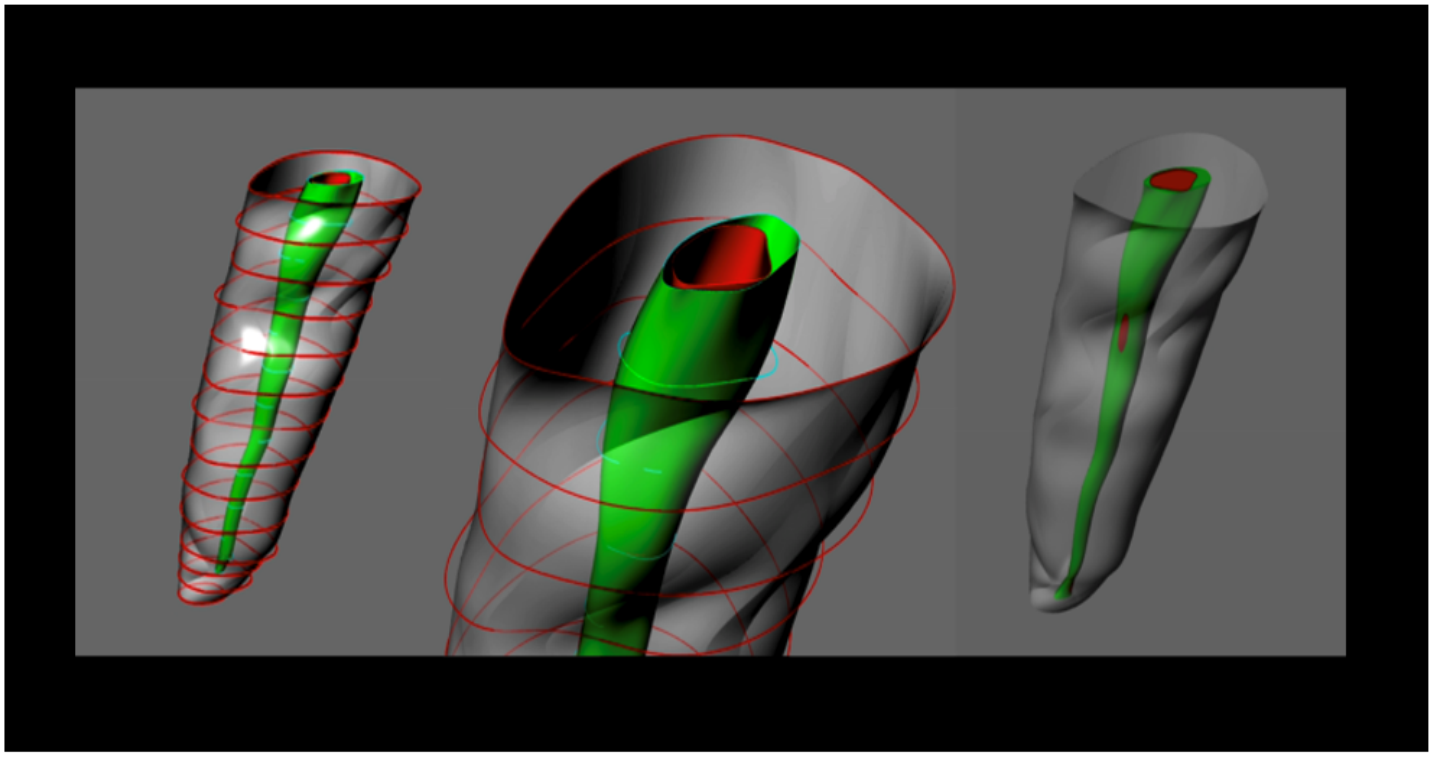

Figure 7

Three-dimensional drawing of root contour and root canal before (red) and after (green) preparation with the Rhinoceros 5.0 3D software using exact measures taken from the CBCT slices.

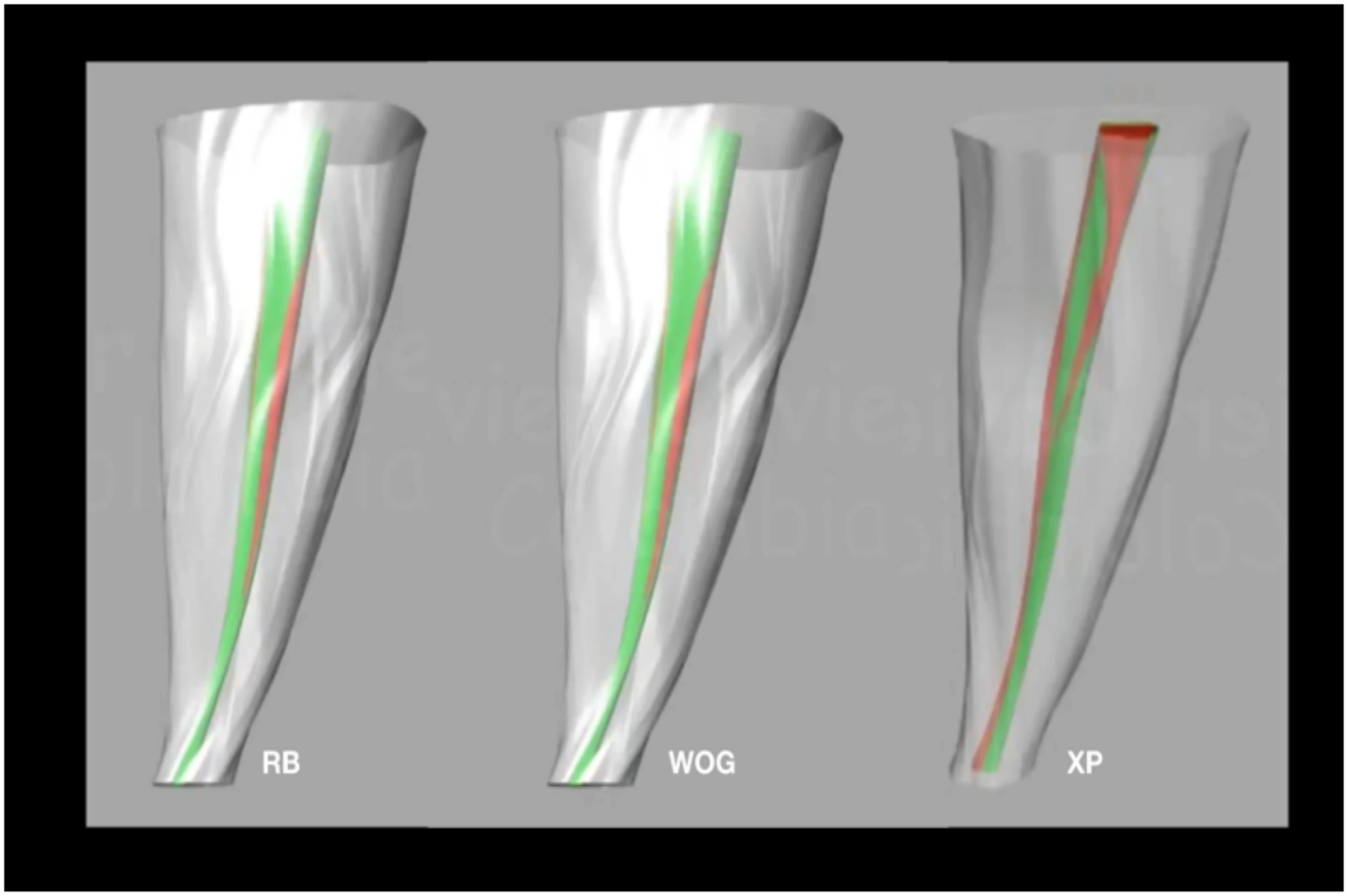

Figure 8

Examples of final 3D reconstructions with details such as the canal colors and the transparency of the roots with prepared canal. RB= Reciproc Blue; WOG= WaveOne Gold; XP= XP EndoShaper.